An Evaluation Of The Shear Bond Strength Of A Flowable Composite Used With An Indirect Bonding Technique

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Tri-Service Orthodontic Residency Program

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Uniformed Services University

June 2018

An Evaluation Of The Shear Bond Strength Of A Flowable Composite Used With An Indirect Bonding Technique

A THESIS

Presented to the Faculty of

Uniformed Services University of the Health Sciences

In Partial Fulfillment

Of the Requirements

For the Degree of

MASTER OF SCIENCE

By

Robert Charles Engel, D.D.S.

San Antonio, TX

June 30, 2018

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ACKNOWLEDGEMENTS

I'd like to thank my research mentor, Dr. Kelly Johnson, for his guidance in developing this research project. I'd also like to show my gratitude to Drs. David Lee and Kraig Vandewalle who were both instrumental in navigating the various forms and supply issues that were faced during my research. Dr. Jisuk Park's statistical knowledge was an invaluable help during this process. Mr. Mike Medrano's laboratory assistance was critical to the success of my project and I hope I didn't break or ruin any of his lab equipment. My co-resident, Dr. Anthony Carbonella, played a large role in the refinement of the experimental design, helping me streamline both my setup and testing processes. I'd like to thank my "Big," Dr. Kevin Menzie, whose ideas helped inspire this research project. I'd like to thank all my co-residents, Drs. Anthony Carbonella, Katherine Darling-Lund, Catherine Kubera, Christina Lilli, Jacob Powell, and Meghan Vanderheiden, who supported me throughout the entirety of orthodontic residency, and who were good sports in dealing with the volume and interesting smells of my supplies.

DEDICATION

To my girlfriend, Amanda, the most caring person I know, who probably would have tried to adopt all the cows that were sacrificed to provide me with the teeth used in this study. To my parents, Richard and Nicole, who have supported me more than anyone and have always had a receptive ear. To my sister, Teresa, her husband, Nick, and my nephew, Jack, for always being there. To Aunt Jackie, my biggest dental advocate, who probably had every orthodontic appliance known to man. To my Uncle Al, who has always pushed me to excel. To Eric, who may technically be my cousin, but is as close to me as a brother, and his wife, Renee. To the rest of my family, here and abroad. To all the friends I have made along the way.

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ABSTRACT

Purpose

The ability to treat patients efficiently is of benefit to both patient and provider. Unintended bracket failures are just one of the potential causes of reduced efficiency in the practice of orthodontics. To reduce bond failures, it is important that each orthodontist chooses a bonding system that achieves a clinically acceptable shear bond strength (SBS) of the adhesive within in the range of 5.9 MPa to 7.8 MPa (Reynolds, 1975). In the military, where treatment time can be limited, ensuring that brackets remain on the teeth is important. As such, military providers should choose adhesives and systems that reliably achieve a clinically acceptable level of SBS. The purpose of this study was to evaluate three bonding systems that are currently available at the Tri-Service Orthodontic Residency Program (TORP), the military orthodontic training site, to determine if there were any significant differences between the groups that might influence future bonding decisions.

Methods

Sixty bovine incisors (Animal Technologies, Tyler, TX) were chosen for use in this study, divided into three groups of twenty. Each group was bonded with a different adhesive system – Direct bonding with Transbond XT (3M Oral Care, St. Paul, MN), indirect bonding with Revolution 2 flowable (Kerr Corporation, Orange, CA), and indirect bonding with Opal Bond Flow (Opal Orthodontics, South Jordan, UT). The brackets were then debonded under shear loading forces with an Instron Universal Testing Machine (Instron, Northwood, MA) to test the SBS of each bracket. Mean SBS and standard deviations were evaluated along with the clinical acceptability rate of each system.

Results

All three groups achieved a mean SBS that exceeded the minimum acceptable SBS value of 5.9 MPa. Brackets bonded directly with Transbond XT yielded the highest SBS and a 100 percent clinical acceptability rate. These values were statistically significant from the values achieved by the Opal Bond Flow group, but not the Revolution 2 flowable group.

Conclusion

The data suggests that the highest performance is achieved by direct bonding with Transbond XT, though not at a level that is significantly higher than Revolution 2 flowable. Due to sources of error identified in the methodology, more studies are needed prior to making conclusions regarding the clinical acceptability of any of the three adhesive systems tested in this study.

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SWA	Straight Wire Appliance
SEP	Self-Etching Primer
SBS	Shear Bond Strength

I. INTRODUCTION

A. Background

The adoption of composite bonding in 1968 changed the practice of orthodontics significantly (Newman *et al.*, 1968). The ability of the orthodontist to bond brackets directly to enamel greatly reduced the amount of chairside time and the hassle of setting up a patient for treatment. This previously required fitting a custom metal band to each tooth individually, followed by the soldering of a bracket to each of the fitted bands prior to cementation. As the purpose of the bands was to hold the bracket to the tooth, composite bonding allowed the elimination of the band altogether and greatly reduced the surface area of the tooth covered by the appliance.

When Andrews developed the straight-wire appliance (SWA), he further changed the nature of the relationship between the bracket and the tooth. At the time, traditional brackets were the same for every tooth. Adjustments in the three planes of spaces were accomplished by placing bends and twists in the archwire. The SWA incorporates these movements into the bracket itself and requires substantially less wire bending. The theory behind the SWA is that *if* the programmed brackets are placed in the correct positions on the facial surfaces of the teeth, when they are aligned on a straight wire passing through all of the bracket slots, the teeth will be in their ideal angulations and inclinations. The key to this system is the accurate bracket positioning and its importance cannot be overlooked (Andrews, 1972).

After composite bonding of orthodontic brackets to teeth was adopted, the traditional method of application was a technique referred to as direct bonding. Today, this method is still in practice and requires cleaning, etching, and priming of the enamel surface followed by placement and orientation of the bracket using either a self- or light-cured composite resin. The operator must attempt to achieve accurate bracket positioning on each tooth with the reduced visualization inherent to working inside the oral cavity. This method has been claimed to require more chair time for the patient and doctor and can potentially be subject to error due to inadequate visualization of the teeth and landmarks needed for orientation.

To overcome these potential pitfalls, a new method of bonding orthodontic brackets was developed called indirect bonding. In this method, brackets are positioned with composite resin on stone casts of the patient's dentition and picked up in a transfer tray. At the bonding appointment, after the teeth have been cleaned, etched, and primed, a flowable composite resin is applied to the cured composite on the bracket bases. The tray is then seated and all the brackets are cured into position at one time. Proponents of this method claim that it saves chair time by bonding all the brackets at once (or in segments). They also claim more accurate bracket placement because the brackets are positioned on a cast of the teeth of which the provider has complete visualization.

In practice, extended treatment time is a burden both for the provider and for the patient. Having accurate initial placement of the bracket positioning decreases treatment time by reducing the need for finishing bends or repositioning of brackets during treatment. Unplanned debonding of brackets can also extend the amount of time needed to reach your end-goal by preventing the desired movements needed between visits. Both of these issues also require increased chair time for the doctor and the patient. Therefore, minimization of bracket positioning errors and debonds is highly desirable in your appliance.

These two methods, direct and indirect bonding, utilize different bonding systems and sequences, and as such the potential exists for one to perform better than the other. Multiple studies have already been performed to compare these two methods of bonding and how they perform in the areas of bond failure, accuracy, and time.

B. Failure rates

Linn looked at the bond strengths between direct and indirect bonding methods and showed no significant difference between bond strengths of a direct bonding method and both a self-cure and light-cure method of indirect bonding (Linn *et al.*, 2006). In 1988, Hocevar also found no difference in bond strengths between the two techniques, provided that no voids were present after indirect-bonding (Hocevar and Vincent, 1988). Deahl looked at failure rates in 2007 and again found no difference in these systems (Deahl *et al.*, 2007). Thiyagarajah published their findings in the Journal of Orthodontics in 2006, also reporting no significant difference between direct and indirect bonding failure rates (Thiyagarajah *et al.*, 2006). A 2013 study by Bozelli also corroborated the claims that no significant difference in bond failures exists between indirect and direct bonding (Bozelli *et al.*, 2013).

A study by Uysal looked at the suitability of flowable composites for bracket bonding. They showed much lower shear bond strengths of flowable composites and advocated against their use for orthodontic bonding (Uysal *et al.*, 2004). Conversely, Park compared a number of flowable composites and received slightly different results. Admira Flow and Aelite Flow had significantly lower shear bond strengths, but a number of other flowable composites had comparable values as Transbond XT, a bonding adhesive used with direct bonding (Park *et al.*, 2009).

Zachrisson showed improved bond strength in brackets where the bases were fitted closer to the tooth surface, which is the case with direct bonding (Zachrisson and Brobakken, 1978). This ideal was also purported by Koo in a 1999 study of placement accuracy (Koo *et al.*, 1999). Zachrisson's study also showed improved adhesive removal and more comprehensive adhesive-base coverage with the direct bonding techniques. However, both techniques were found to deliver satisfactory results.

C. Accuracy of bracket placement

Hodge compared the accuracy of bracket placement between indirect and direct bonding by conducting a randomized prospective study of 26 consecutive patients. They bonded the patients either by indirect or direct means and then before and after photographs were used to determine errors in placement from ideal. They found a similar incidence of errors between the two methods (Hodge *et al.*, 2004).

Koo found indirect techniques to be more accurate in the vertical dimension but showed no significant differences in either angulation or mesiodistal positioning. Both methods of bonding were shown to have errors from ideal placement (Koo *et al.*, 1999).

D. Time cost

Bozelli's 2013 study looked at the two bonding systems to determine the amount of time invested with each technique. For direct bonding, they looked at the clinical chairside time. For indirect bonding, they did the same, but also evaluated the laboratory time needed to complete the setup. In total, they found the amount of time needed to complete indirect bonding was greater than direct bonding. However, comparing the bracket setup times for direct and indirect, there was no difference. Also, they found that chairside time was reduced when bonding indirectly (Bozelli *et al.*, 2013).

In Deahl's sample of 11 orthodontic offices, five of which used a direct technique and six that used indirect bonding, no difference was noted in debond incidence. They also noted that the total visits and treatment duration were equivalent between the two groups (Deahl *et al.*, 2007).

II. OBJECTIVES

A. Overall Objective

As this review of the literature would appear to illustrate, the performance of direct and indirect bonding techniques is of great interest to the orthodontic community. As providers seeking to provide efficient and effective treatment for patients, ensuring that one is using a quality bonding system is of the utmost importance. Many of the studies comparing these two systems use Transbond XT as the direct bonding adhesive. Likewise, for direct bonding at the Tri-Service Orthodontic Residency Program (TORP) at Lackland Air Force Base, Transbond XT is utilized along with a 34% phosphoric acid etch (DENTSPLY International, York, PA) and Transbond SEP primer (3M Oral Care, St. Paul, MN). For indirect bonding, TORP uses Revolution 2 flowable composite as the bonding interface between Transbond XT and the Transbond SEP primer. Indirect bonding is not listed as one of the approved uses of Revolution 2 flowable composite by the manufacturer. Consequently, in this literature search, no studies were found that looked at the efficacy of Revolution 2 flowable composite as an indirect bonding composite. Opal Bond Flow is another flowable composite available to military orthodontists and, unlike Revolution 2, it is rated for use in indirect bonding by its manufacturer.

The purpose of this study is to evaluate the shear bond strength of Revolution 2 flowable composite when used for indirect bonding of orthodontic brackets as compared to the shear bond strength of Opal Bond Flow used indirectly and of Transbond XT used in a direct bonding method.

B. Hypotheses

Null Hypothesis: There will be no significant difference in the shear bond strength among Revolution 2 flowable composite, Opal Bond Flow, and Transbond XT.

Research Hypothesis: There will be a significant difference in the shear bond strength among Revolution 2 flowable composite, Opal Bond Flow, and Transbond XT.

III. MATERIALS AND METHODS

A. The Teeth

This study was performed using bovine incisors. Three hundred bovine incisors were procured and stored in distilled water prior to and throughout the protocol. Sixty teeth were chosen based on a set of inclusion criteria used to ensure suitability with the protocol design and adequate bonding environment. Teeth were excluded if there was evidence of coronal caries, enamel fractures or hypomineralization in the bonding area, gross staining extending into the bonding area, or less than eighty percent of the root remaining.

Following selection of sixty teeth that met the inclusion criteria, the teeth were divided at random into twelve sets of five. Each set of five bovine incisors was placed in a plastic bag with distilled water and sealed until ready to be embedded in acrylic. The twelve sets were then further divided into three groups corresponding to the different treatment modalities. Group 1 was comprised of sets one through four, twenty teeth in total, and was assigned for indirect bonding with Revolution 2 flowable composite. Group 2 was comprised of sets five through eight, twenty teeth in total, and was assigned for indirect bonding with Opal Bond Flow flowable composite. Group 3 was comprised of sets nine through twelve, twenty teeth in total, and was assigned for direct bonding with Transbond XT.

Figure 1. Fabrication of acrylic base former (Jigs placed on container lid)

B. Embedding the Teeth

I. Creating the base

Red boxing wax (Coltene Whaledent, Cuyahoga Falls, OH) was used to create a rectangular former that would house the roots of five aligned bovine incisors. White orthodontic stone (Whip Mix Corporation, Louisville, KY) was poured into the wax former and allowed to set. This process was repeated to produce two identical stone blocks. The two blocks were placed parallel on the lid of a 700mL plastic storage container (Figure 1). A hole was cut in the bottom right corner of the container and the base was fit onto the lid upside down.

Figure 2. Setting of Double Take material during fabrication of base former

700mL of Double Take duplicating material (Ivoclar Vivadent, Amherst, NY) were mixed (350mL of Base, 350mL of Catalyst) for 45 seconds and poured through the hole in the base at a height of 30-40cm per manufacturer instructions. The base was filled and the Double Take was allowed to set for 45 minutes (Figure 2). Once the Double Take was set, the lid was removed and the two stone blocks were removed. This left two identical troughs in the duplicating material that would act as the bases for the acrylic used to embed the teeth.

Figure 3. Bovine incisor setup.

II. Setting Up the Teeth

For each set of teeth, the five incisors were removed from their distilled water and dried with air. Using sticky wax (Miltex, York, PA), each tooth’s facial surface was affixed to the flat aspect of a tongue depressor. Teeth were positioned next to each other in a generally straight line and with incisal corners approximating each other (Figure 3). The facial surfaces were positioned such that the area to be bonded with a bracket would be contacting the tongue depressor. This would assure that the brackets could be placed in the same plane to assist with shear testing.

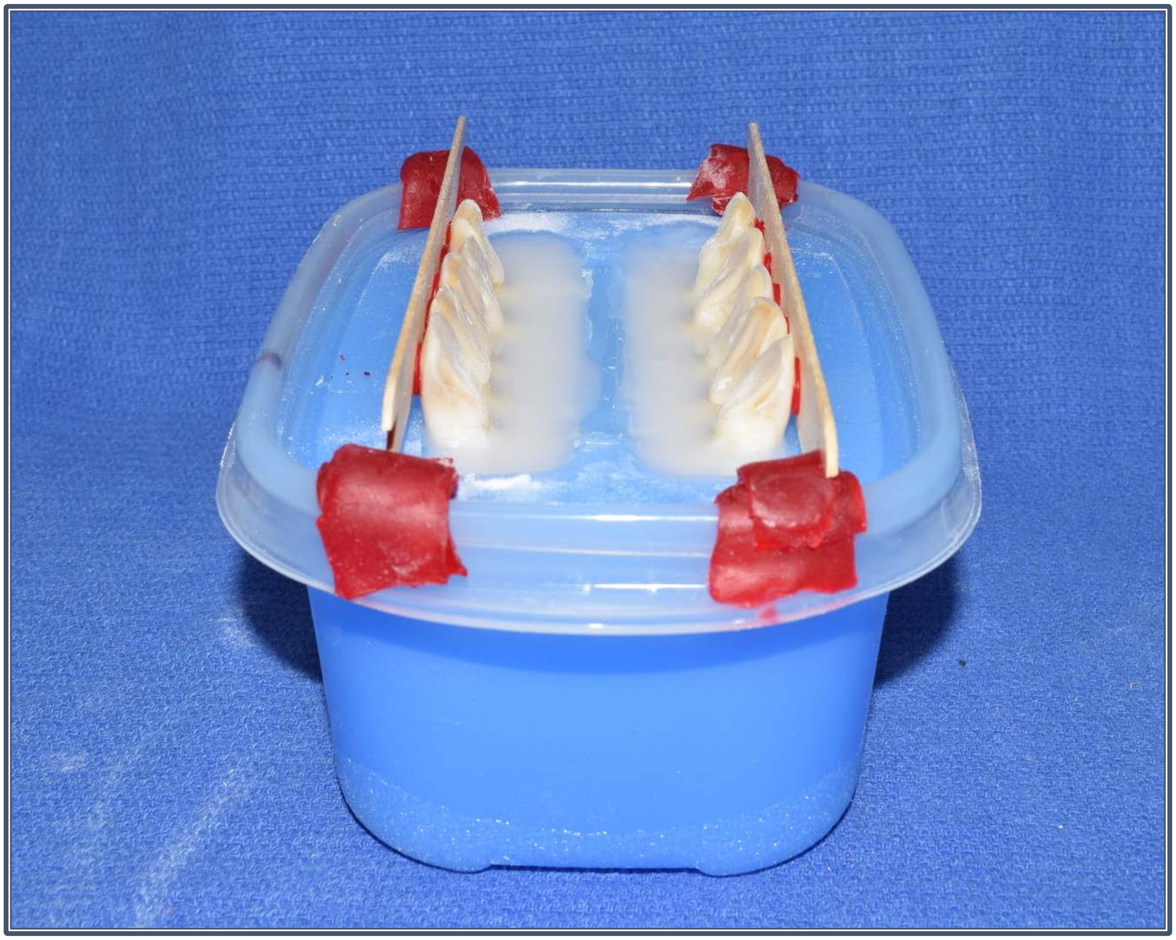

Figure 4. Formation of acrylic blocks

The tooth-tongue depressor complex was then waxed to the acrylic base former such that the tongue depressor's flat surface was vertical, the facial surfaces extended just slightly beyond the base, the cementoenamel junctions approximated the top edge of the former, and the roots protruded into the former. Acrylic (Great Lakes Orthodontics, Ltd., Tonawanda, NY) was then added into the former using a salt-and-pepper technique until the base was filled (Figure 4).

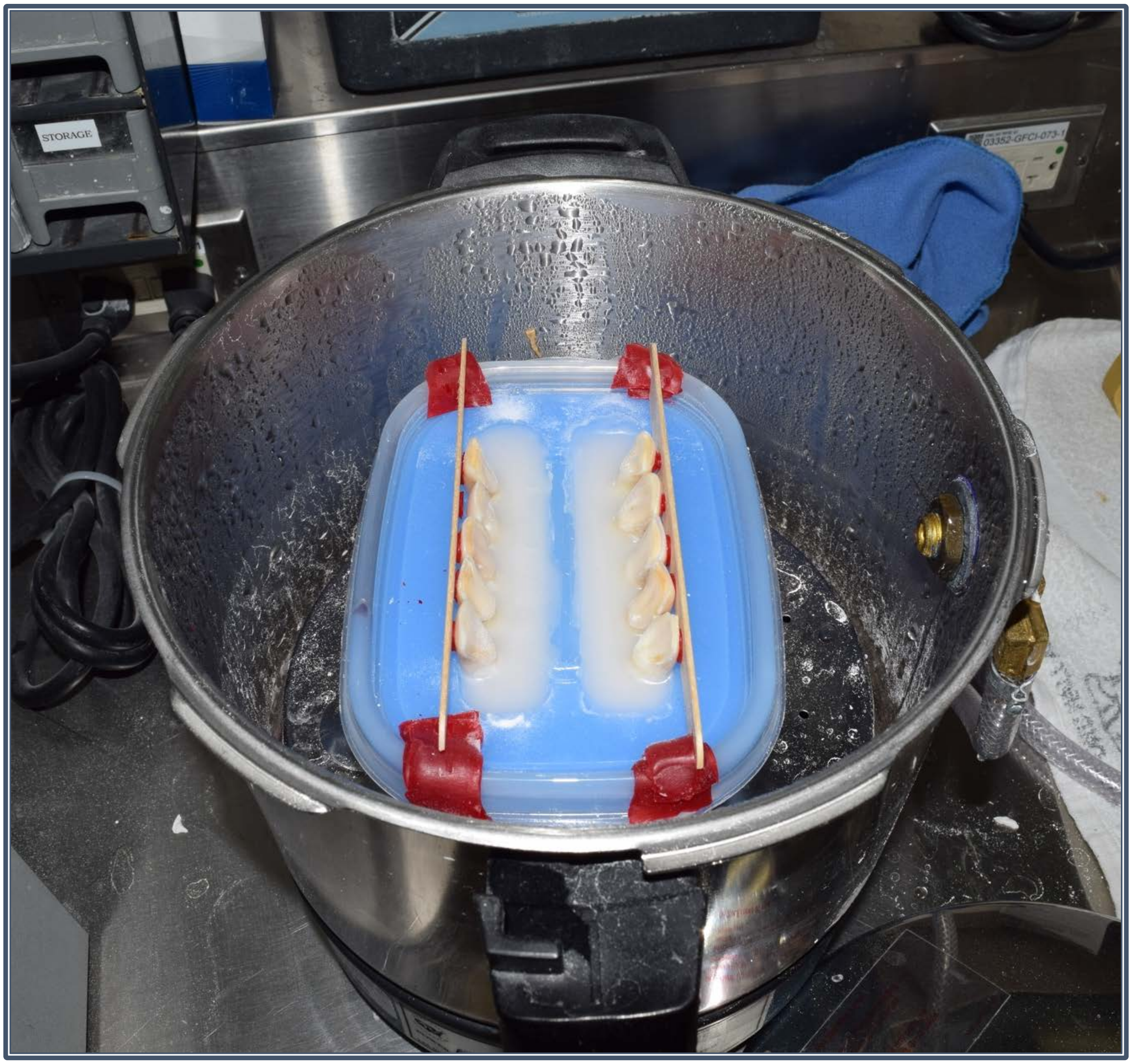

Figure 5. Curing acrylic in pressure pot

The acrylic was then cured in a pressure pot at 20 psi for twenty minutes (Figure 5). Upon removal from the pressure pot, the setup was removed from the former and the tongue depressor was detached from the teeth.

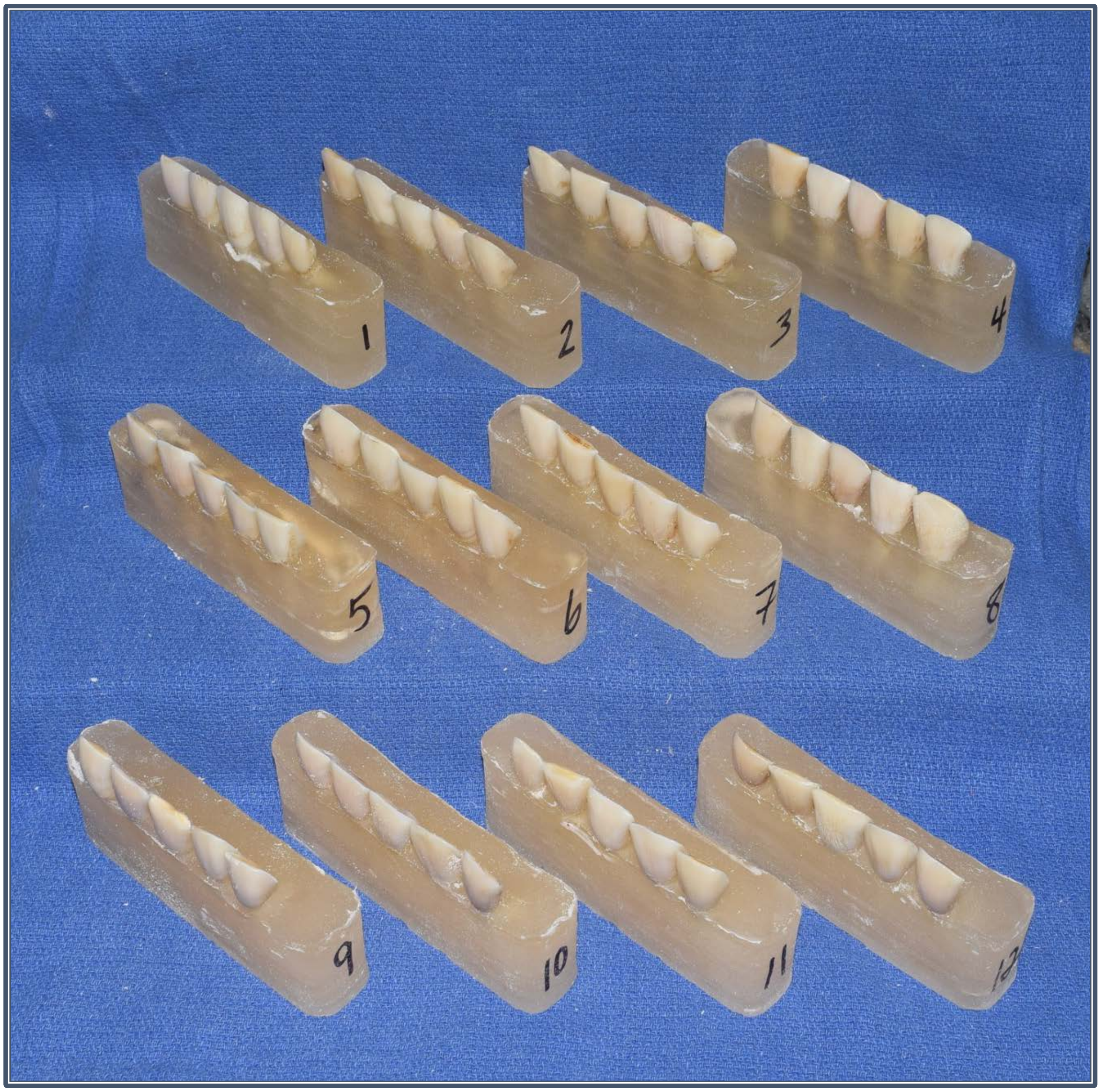

Figure 6. Bovine incisor setups prior to bonding

A steamer was used to remove the wax remnants from the teeth. Excess acrylic flash was removed with an acrylic bur. This method yielded twelve acrylic blocks, each of which contained five bovine incisors with the facial surfaces exposed for bonding (Figure 6).

Figure 7. Custom Triad impression tray

C. Indirect Bonding of Groups 1 and 2

I. Making impressions

Due to the size and configuration of the tooth setup, standard impression trays were inadequate to make alginate impressions of the teeth for indirect bonding. Using a pilot setup of teeth, two custom trays were fabricated using clear Triad custom tray material (DENTSPLY International, York, PA). The teeth were covered with two layers of red boxing wax prior to forming the Triad. The trays were cured for seven minutes in a Triad 2000 curing unit (DENTSPLY International, York, PA) and then removed from the teeth for use (Figure 7).

Wax was placed in the gingival embrasures of the tooth setups for both groups 1 and 2 in order to block out excessive undercuts.

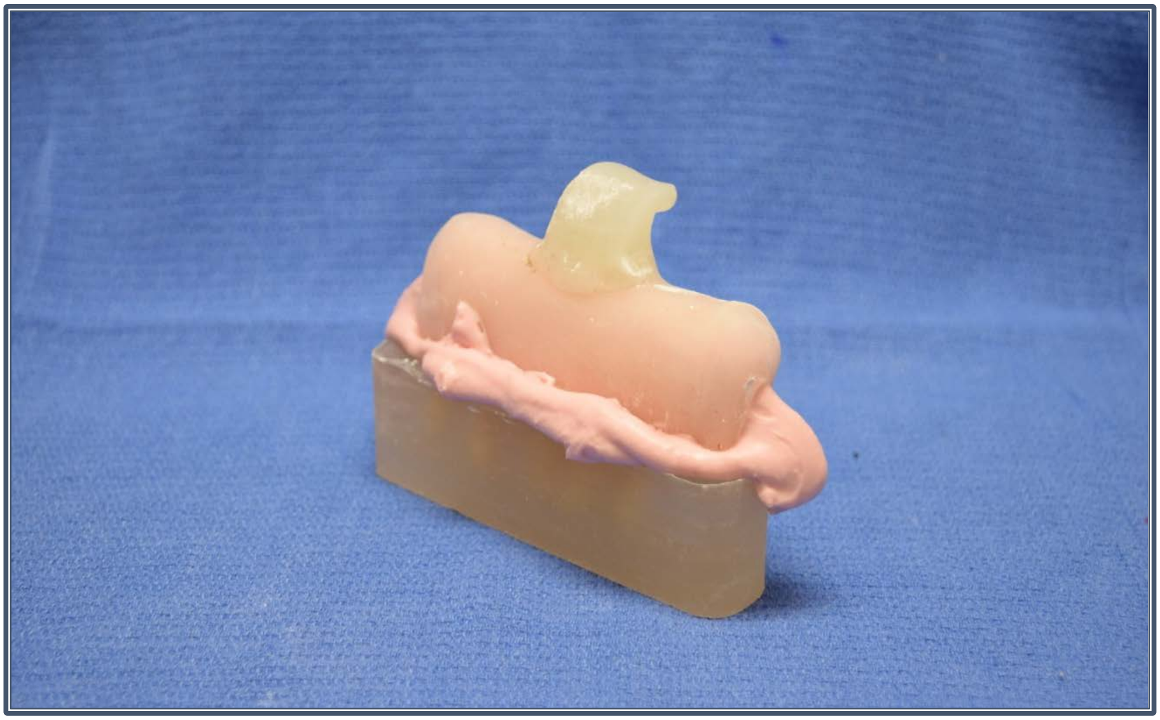

Figure 8. Taking impression of incisor setup

Jeltrate Fast-Set alginate impressions (DENTSPLY International, York, PA) were made of each setup in both of the indirect bonding groups (Figure 8). Each impression was poured up in white orthodontic stone and allowed to set. The impressions were separated from the casts and the casts were trimmed of excess stone flash. Following trimming, the eight casts were allowed to dry fully prior to performing the indirect bond setup.

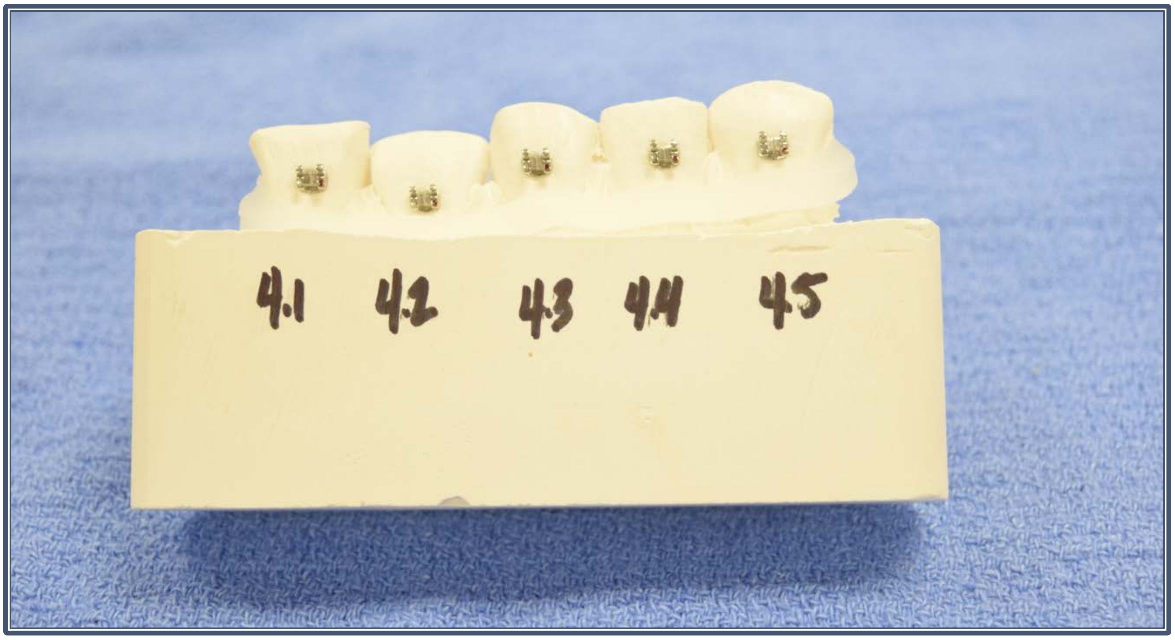

Figure 9. Indirect bonding setup

II. Indirect bonding setups

When the casts were fully dry, a layer of Al-Cote separating medium (DENTSPLY International, York, PA) was painted on the facial surfaces of all the teeth. The Al-Cote was air thinned and allowed to dry. One 3M Unitek #8 precoated bracket (3M Oral Care, St. Paul, MN) was then placed on the facial surface of each tooth. The bracket was placed into its final position and fully seated. The excess adhesive was removed. The casts were then placed into a Triad curing unit for six minutes to cure the adhesive.

Rope wax was placed around the casts approximately two millimeters apical to the brackets on the facial surface and five millimeters apical to the incisal edge on the palatal surface. The rope wax acted as a dam for the tray material to prevent it from extending too far apically (Figure 9).

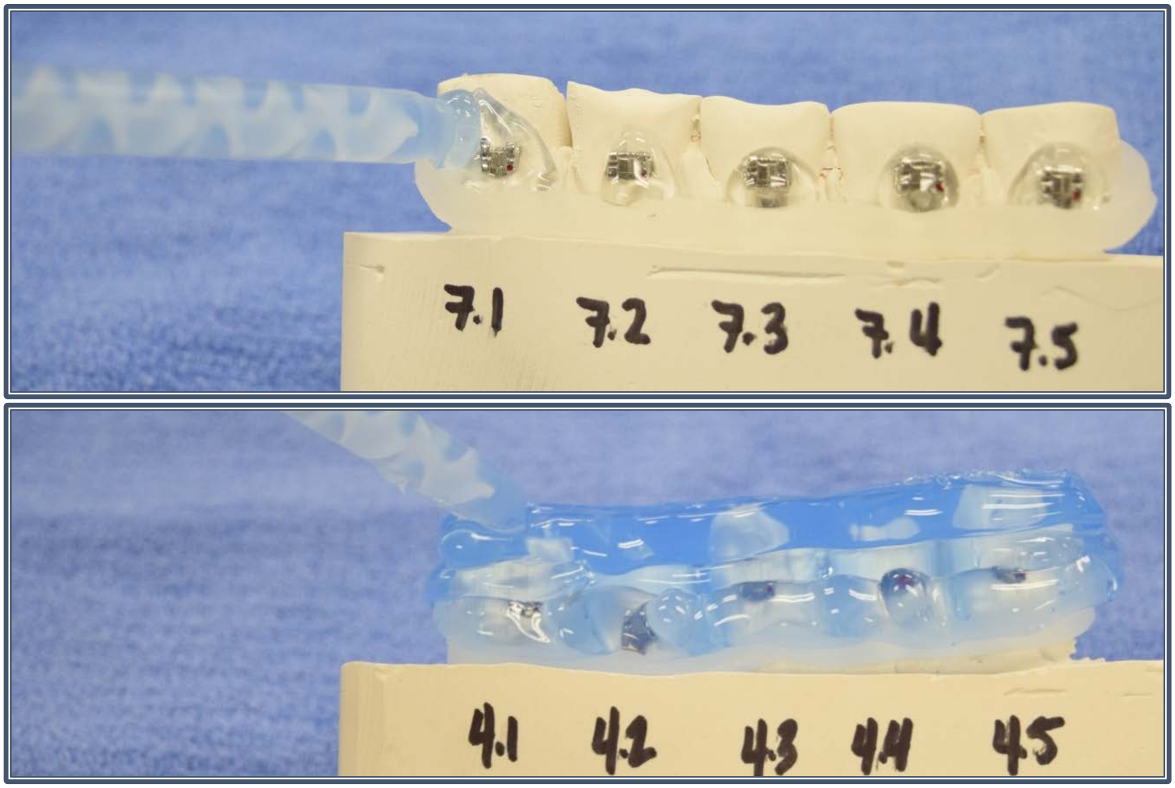

Figure 10. Fabrication of Emiluma/Lumaloc transfer tray

To create transfer trays, the Emiluma/Lumaloc system (Opal Orthodontics, South Jordan, UT) was used. This two-step system employs a low tear resistant silicone (Emiluma) followed by a more rigid silicone (Lumaloc). A small amount of Emiluma was expressed directly onto each bracket. Immediately after this, Lumaloc was dispensed over the Emiluma, filling in all areas inside the wax dam, to create the rigid superstructure for the tray (Figure 10). The silicone was then allowed to set per the manufacturer's instructions. The casts/trays were then placed in water for twenty minutes to allow the separating medium to dissolve. The trays were removed and the brackets bases were examined and steamed to remove any stone deposits or contaminants. The transfer trays were allowed to dry prior to performing the bonding procedure.

III. Indirect bonding

The facial surfaces of the teeth to be bonded were cleaned using pumice (Preppies, Henry Schein, Melville, NY) and rinsed completely. Thirty-four percent acid etchant gel was then placed on the facial surfaces and allowed to work for twenty seconds. The etched teeth were rinsed and dried. The facial surfaces of the teeth were painted with Transbond Self-etching Primer for 3-5 seconds and then the primer was air thinned. A thin layer of Revolution 2 flowable composite was applied to the bases of the brackets in Group 1. Opal Bond Flow was applied to the brackets in Group 2. Each transfer tray was seated on its corresponding setup and the adhesive was cured for nine seconds per tooth. The transfer trays were removed and the brackets were cured for an additional six seconds each, three seconds on the mesial and three seconds on the distal. All of the procedures listed above were performed for one set at a time (Figure 11).

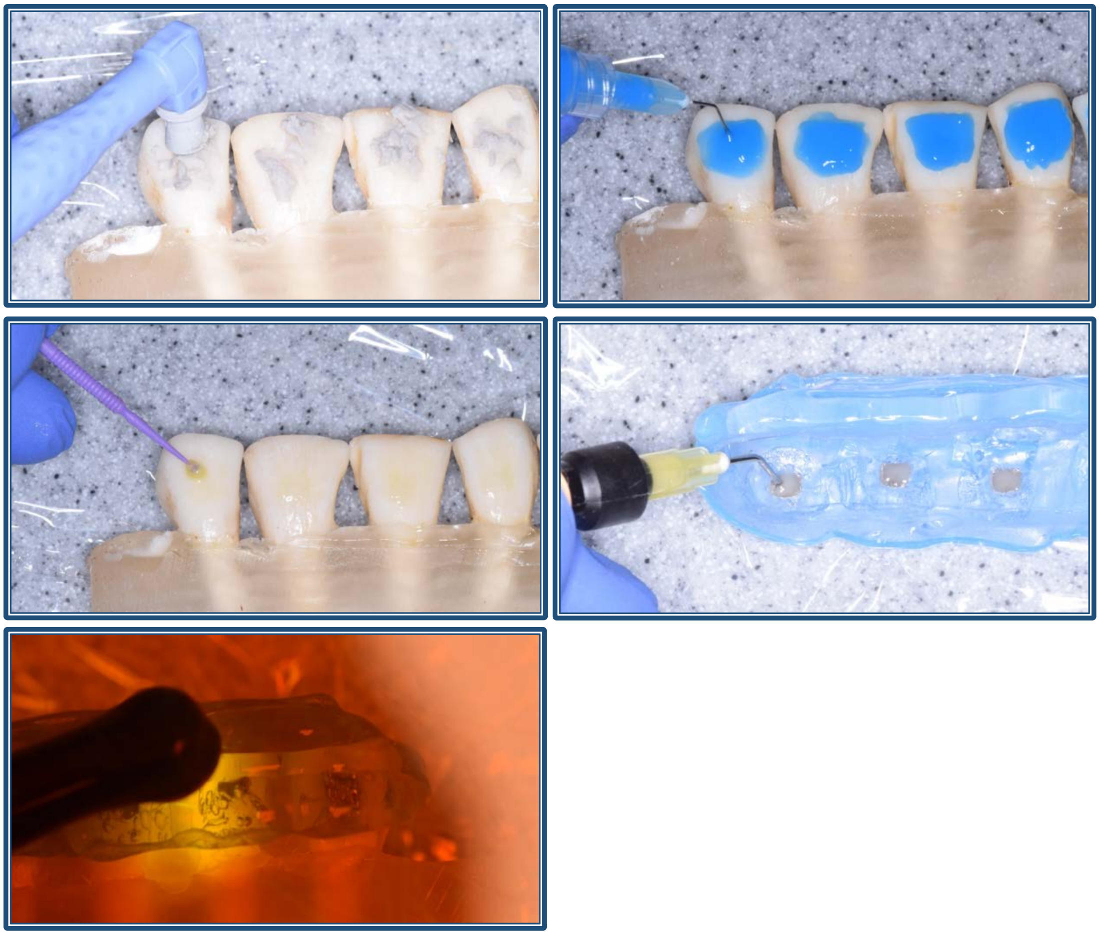

Figure 11. Indirect bonding technique

D. Direct Bonding of Group 3

The facial surfaces of the teeth to be bonded were cleaned using pumice and rinsed completely. Thirty-four percent acid etchant gel was then placed on the facial surfaces and allowed to work for twenty seconds. The etched teeth were rinsed and dried. The facial surfaces of the teeth were painted with Transbond Self-Etching Primer for 3-5 seconds and then the primer was air thinned. One 3M Unitek #8 precoated bracket was then placed on the facial surface of each tooth. The bracket was placed into its final position and fully seated. The excess adhesive was removed. Each bracket was cured for a total of twelve seconds each, three seconds per side (incisal, gingival, mesial, distal). All of the procedures listed above were performed for one set at a time (Figure 12).

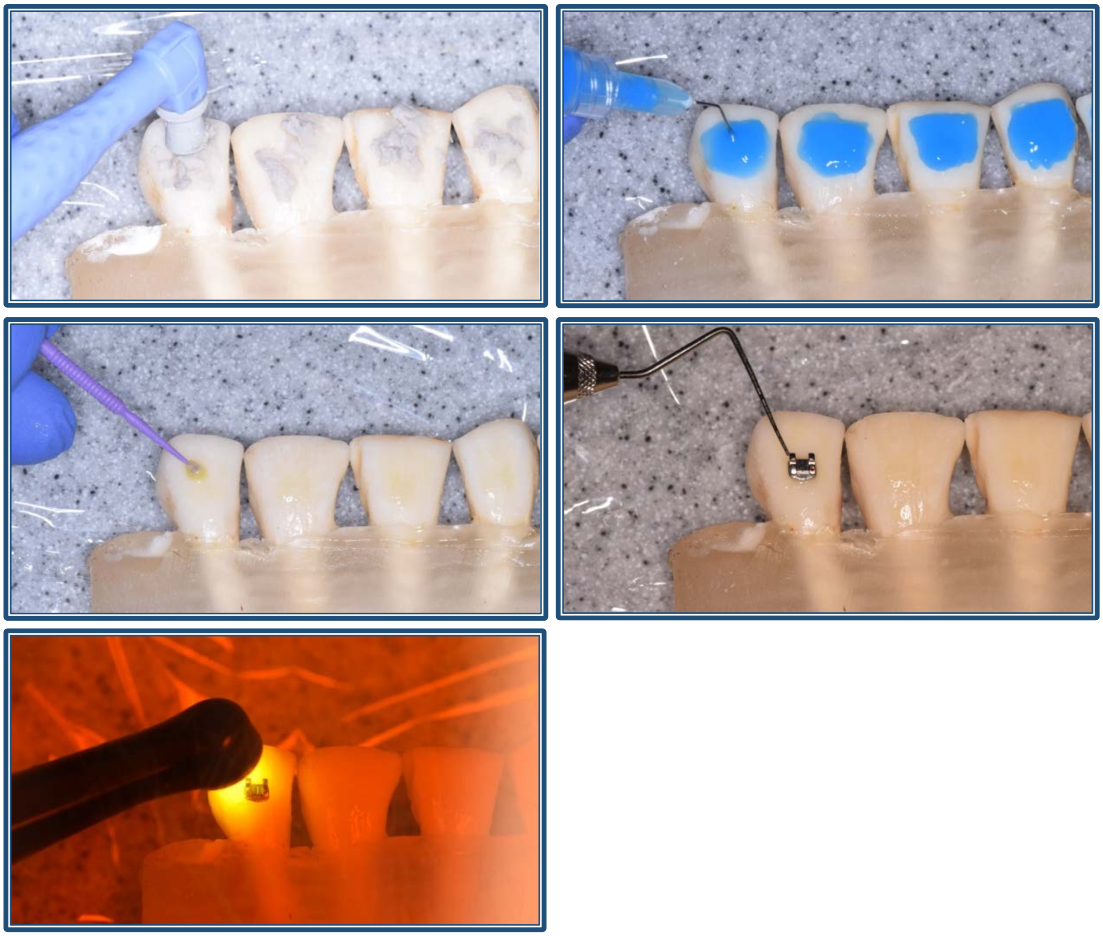

Figure 12. Direct bonding technique

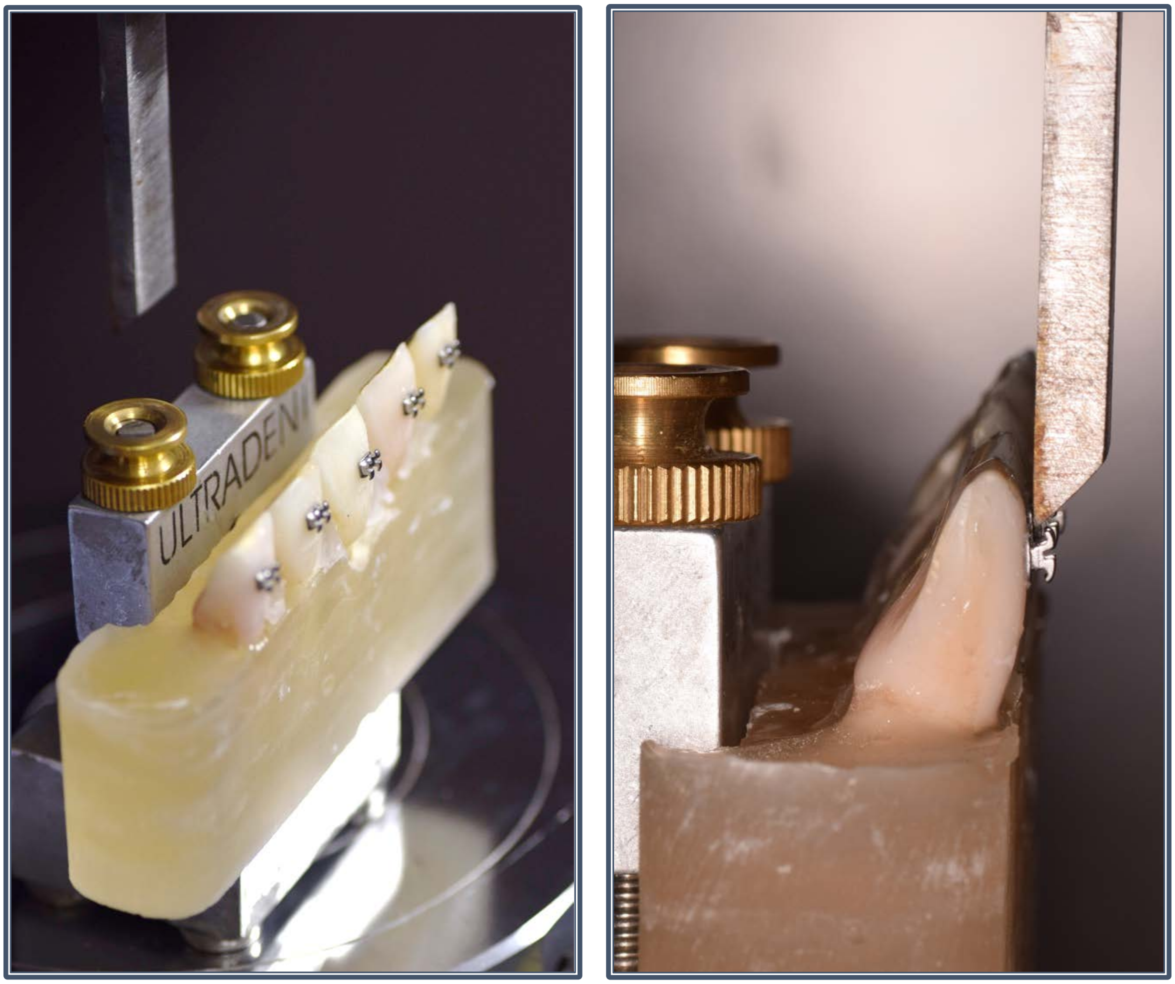

Figure 13. Block secured on mounting jig with crosshead in position

E.   Shear Bond Strength Testing

To accommodate the Instron platform mounting jig (Ultradent, South Jordan, UT), sections of the posterior aspect of the acrylic blocks were removed. The bonded acrylic-tooth blocks were then mounted in the Instron Universal Testing Machine holder and positioned such that the crosshead would contact the brackets between the bonding pad and the superior tie wings (Figure 13).

Figure 14. Shear loading of brackets with Instron

The crosshead speed was set to 1 mm/min. When each test was initiated, the crosshead would lower until contact was made with the bracket. The load would then increase until the bracket was debonded from the tooth (Figure 14). The maximum load achieved for each test was recorded on computer software in units of newtons (N).

Each measurement was then converted into megapascals (MPa) using the following equation:

$$1\ N/mm^2 = 1\ MPa$$

The maximum load in newtons was divided by the surface area of the bracket's bonding pad (surface area = 10.52 mm^2) to yield a measurement in megapascals. The maximum shear bond strength of each of the sixty samples was recorded and then subjected to statistical analysis.

F. Statistical Management of Data

The outcome variable, shear bond strength, was assessed for normality by the Shapiro-Wilks test, which was normally distributed. Normal variables are summarized by the mean and standard deviation (SD). A one-way analysis of variance (ANOVA) was used to compare the mean differences in shear bond strength among the three different materials (Revolution, Opal Bond Flow, and Transbond XT). Post Hoc tests (Multiple Comparison tests) were conducted using the Bonferroni correction. The shear bond strength score was coded as 1 for clinically accepted and 0 for clinically unacceptable using the minimum clinical success with 5.9 MPa (Reynolds, 1975). The clinically acceptable rates were compared using the Fisher's Exact Test and post-hoc multiple comparison tests (Bonferroni correction).

Group	Mean	SD	Minimum	Maximum
G1: Indirect bonding Revolution	9.41	4.95	1.54	17.70
G2: Indirect bonding Opal Bond Flow	7.18	4.29	1.30	17.08
G3: Direct bonding Transbond XT	10.97	3.30	6.32	18.55

Table 1. Descriptive statistics for the three test groups

IV. RESULTS

Following bond failure of each bracket due to shear loading with the Instron Universal Testing Machine, the maximum force value achieved was recorded in newtons. Each value was then converted into megapascals by dividing the force in newtons by the surface area of the bracket pad ($10.52mm^2$). The shear bond strength data for the samples in each of the three test groups can be seen in Table 2, which can be found in Appendix A. The mean and standard deviation for each group is in Table 1. Group 3 had the highest mean SBS at 10.97 (SD 3.30) MPa. Group 2 had the lowest mean SBS at 7.18 (SD 4.29) MPa. The distributions of the data are illustrated graphically in Figure 15.

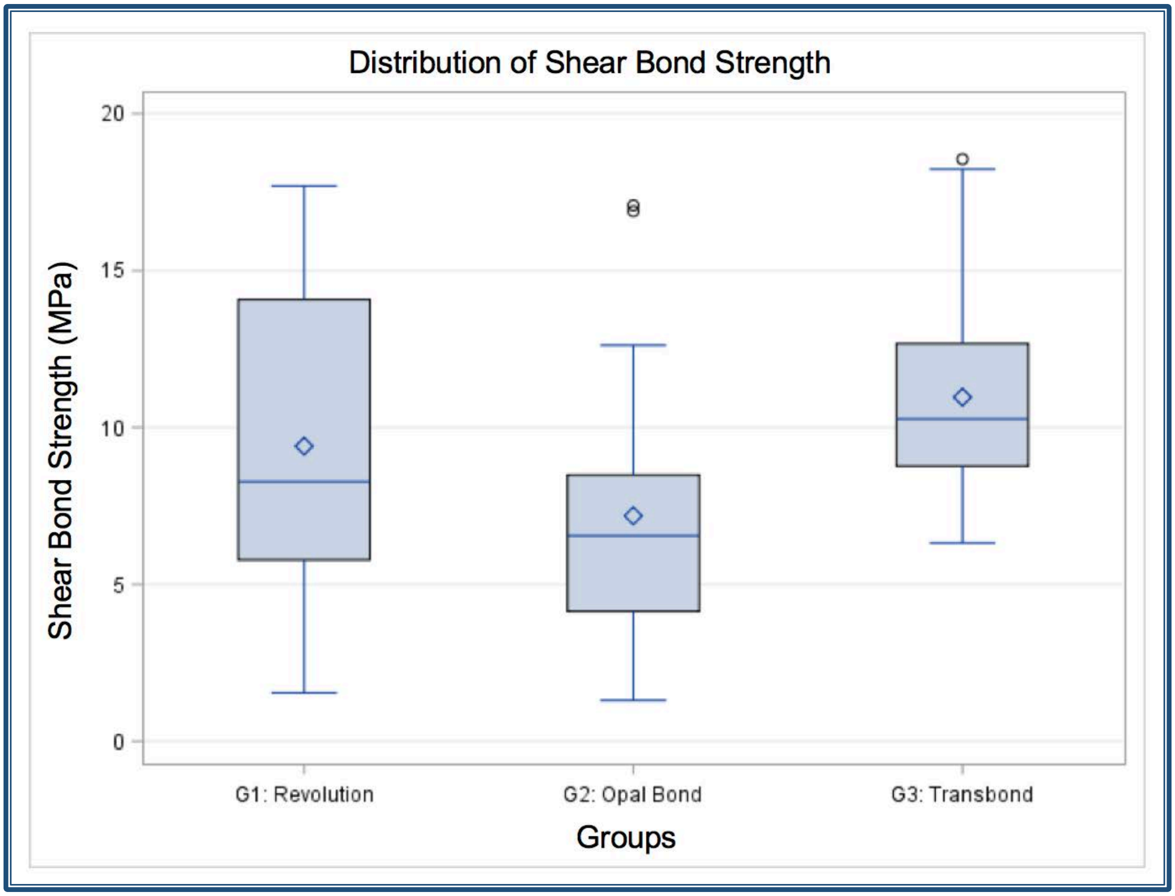

Figure 15. Box plots of shear bond strength data

A one-way ANOVA was conducted to compare the difference in shear bond strength among 3 different materials (Revolution, Opal Bond Flow, and Transbond XT). There was a significant effect of materials in shear bond strength at the $p < .05$ level [$F(2, 57) = 4.026$, $p = 0.023$]. Post hoc comparisons using the Bonferroni correction indicated that the mean score for Transbond XT (Mean = 10.97, SD = 3.30) was significantly different than the Opal Bond Flow group (Mean = 7.18, SD = 4.29). However, the Revolution group (Mean = 9.41, SD = 4.95) did not significantly differ from the Opal Bond Flow and Transbond XT groups.

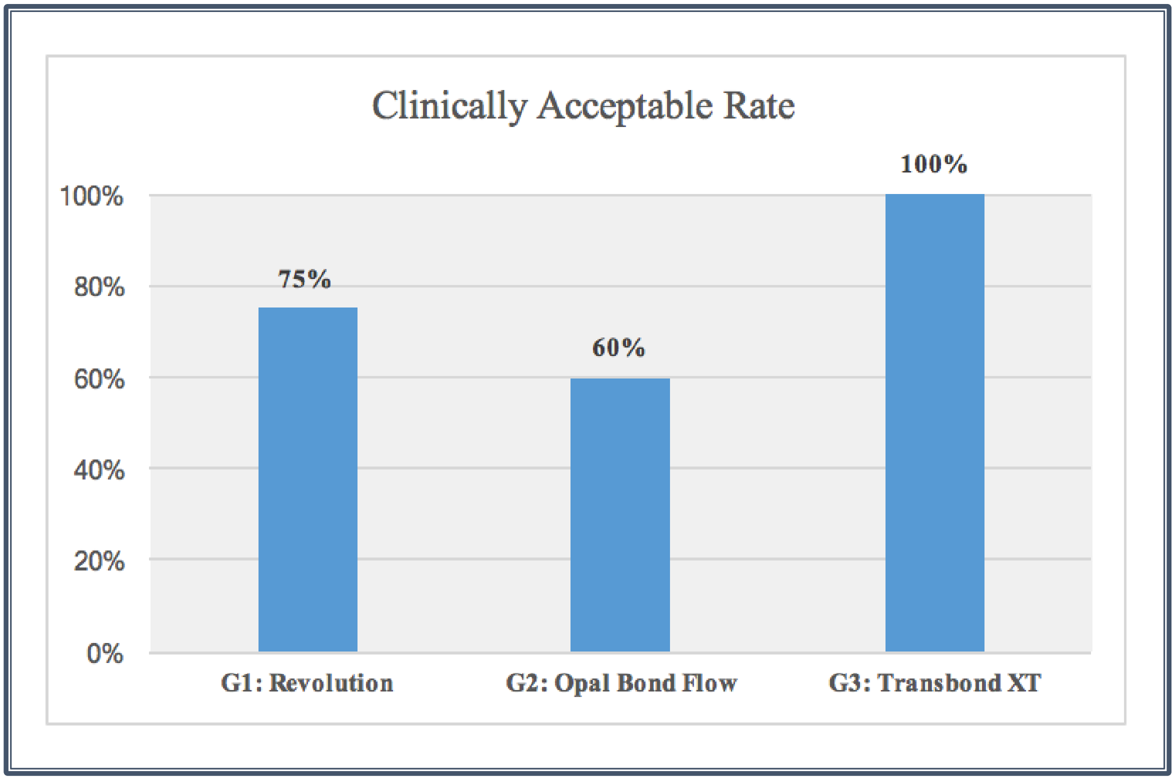

Figure 16. Clinical Acceptability Rates

The clinical acceptability rate was evaluated for each group (Figure 16). Depending on if a sample's SBS strength met the minimum value of 5.9 MPa or fell below it, it was assigned a value of 1 or 0, respectively. The percentage of samples in each group that were assigned a value of 1 was then determined and this was deemed that group's clinical acceptability rate. Group 3 had a clinical acceptability rate of 100 percent indicating that every sample in the group met or exceeded the shear bond strength threshold of 5.9 MPa. Groups 1 and 2 each had clinical acceptability rates less than 100 percent, with only 75 and 60 percent of the samples achieving the clinically acceptable SBS of 5.9 MPa, respectively.

V. DISCUSSION

The adoption of composite bonding in orthodontics in 1968 was an incredible technological advancement that greatly impacted the specialty. The success of modern appliances is predicated on the system maintaining its integrity throughout treatment. Failure in composite bonding leading to bracket bond failure has the potential to slow down treatment and decrease the efficiency of the clinician. It is in both the patient's and the orthodontist's best interests to choose an adhesive that can predictably provide shear bond strengths that meet a clinically acceptable value. This value was reported to be 5.9 MPa by Reynolds. By choosing bonding materials that perform adequately, a provider's efficiency can be improved. In a military setting, where efficiency is necessary to return service members to duty as soon as possible, choosing appropriate materials is paramount. It was this knowledge that guided the research performed in this study.

The shear bond strengths of three clinical orthodontic bonding systems were tested in this study. Group 1 tested Revolution 2 flowable composite used with an indirect bonding technique. Group 2 tested Opal Bond Flow flowable composite used with an indirect bonding technique. Group 3 tested Transbond XT used with a direct bonding technique. Twenty samples were tested per group for a total of sixty samples. The mean shear bond strengths and standard deviations were determined for each group, as well as the clinical acceptability rates.

Group 3 performed the best of the three groups in terms of shear bond strength. The mean shear bond strength of 10.97 MPa (SD 3.30) was the highest of the tested groups. Group 1 had a lower mean shear bond strength of 9.41 MPa (SD 4.95), but this difference was not significant from Group 3. Group 2 had the lowest mean shear bond strength at 7.18 MPa (SD 4.29) and was significantly different from Group 3, but not from Group 1. While there were differences between the three groups, all three exceeded the minimum threshold SBS of 5.9 MPa. Based solely on the statistical means, the orthodontic clinician could choose any of the three bonding systems and feel confident that bracket debonds were not due to inadequacy of the composite strength. The variability of the data, however, suggests otherwise.

Looking at the range of the data, one can see that there are many samples that did not reach this minimum threshold of shear bond strength. Group 1 recorded values as low as 1.54 MPa and Group 2 had values as low as 1.30 MPa. These clinically unacceptable values led to further evaluation into the meaning and clinical applicability of the data.

As described earlier, each sample was compared to the minimal threshold of 5.9 MPa and assigned a 1 or a 0 depending on if the sample value was above or below the threshold, respectively. For each group, the percentage of samples that met the minimal threshold was calculated. This was deemed the clinical acceptability of the group. Group 3 yielded a clinical acceptability of 100 percent, indicating that every sample met or exceeded the minimal SBS of 5.9 MPa. Group 1's clinical acceptability was 75 percent and Group 2's was 60 percent.

Similar to the mean shear bond strength, Group 3 was significantly different from Group 2, but Group 1 was not significantly different from either Groups 2 or 3.

Applied to the clinical setting, this would suggest that 100 percent of brackets bonded directly with Transbond XT would achieve an acceptable level of shear bond strength. Likewise, only 75 percent of brackets bonded indirectly with Revolution 2 flowable composite would achieve the same level. Only 60 percent of brackets bonded indirectly with Opal Bond Flow would meet a clinically acceptable level of shear bond strength. One might liken the clinical acceptability rate of the composite adhesive to its reliability. Based on the results of the trials, the most reliable bonding system is direct bonding with Transbond XT. The clinician could feel confident that any debonds while using this system would not be due to inadequate bond strength. The other two systems offer lower reliability. Orthodontists could not be sure if their adhesive is achieving an acceptable level of strength. In the case of Opal Bond Flow, almost half of the brackets were not bonded with a clinically acceptable level of strength. When choosing bonding materials to reduce bond failures and increase efficiency, this study suggests that direct bonding with Transbond XT would be the ideal bonding system of the three tested.

With the widespread acceptance of indirect bonding, what then are the implications of this study? The direct bonding group had both the highest mean SBS and clinical acceptability rate. Given this information, should an orthodontist choose one of the indirect bonding systems tested in this study? It was stated earlier that the mean SBS of Group 3 was statistically different from Group 2, but not Group 1. This does not mean that Transbond XT is better than Opal Bond Flow. All that is necessary for a bonding system is for it to achieve a SBS of 5.9 MPa. In this case, all three means are above the clinically acceptable level and as such are all appropriate choices for bonding.

The implications of the clinical acceptability rate are different from the mean SBS. There is no threshold rate to distinguish acceptable from unacceptable. In general, the higher the better. Applying these rates to clinical scenarios, each rate represents the number of brackets that meet the clinical threshold out of every 100 brackets. The analysis shows that Group 3 was again statistically different from Group 2, but not Group 1. One might make the conclusion then, that Opal Bond Flow is not ideal for clinical use based on its significantly lower acceptability rate. One might also conclude that direct bonding with Transbond XT is the most ideal system of the three based on its perfect acceptability rate, but remember that it was not determined to be statistically significant from Group 1. These conclusions must be questioned once the sources of error are taken into account.

One potential source of error can be seen in the use of indirect bonding and comparing it to direct bonding. Direct bonding allows visualization of the bracket and adhesive at the time of cure. Adaptation of the bracket pad to the tooth surface can be verified and the excess cement cleaned appropriately. Indirect bonding inherently involves an amount of faith that the bracket and cement are adapted similarly to a direct technique. The adaptation of the bracket pad to the tooth throughout the entirety of the curing cycle cannot be intimately visualized through the indirect bonding tray. Slight movement of the tray or inaccuracy of the adaptation may be unnoticed and could lead to a poor bond.

Another potential source of error in the indirect bonding technique that may lead to a lower SBS than directly bonded brackets is the depth of cure. During direct bonding, the curing light can be placed as close to the adhesive as is physically possible and the light does not pass through a medium before hitting its target. With indirect bonding, the light is held at a farther distance from the adhesive due to the thickness of the tray and the light beam must travel through the tray medium prior to hitting its target. Variations in the thickness of the tray and the light transmittance are limitations that may lead to a lesser depth of cure that are not encountered in direct bonding.

The shear bond testing had other sources of error that may have influenced the data in this study. The teeth in each of the twelve sets were tested while remaining mounted in their original acrylic blocks. The acrylic blocks were wider than the dimension of the mounting jig which may have led to a more unstable application of force on the outer brackets as compared to the central brackets. In other words, the outside brackets were cantilevered and the force application would have had a larger lever arm at these brackets. This could have led to inaccurate measurements if the block were to have tipped upon loading.

The dimensions of the mounting jig only allowed a grip depth of approximately three millimeters. Similar to the complication encountered with the width of the acrylic blocks, their depth may have led to undesirable tipping in an anterior direction. Once again, this is due to a load placed on a cantilevered bracket that was not placed directly over the mounting jig base.

Another source of error was the potential variation in the application of the shear force to the bracket base. An inaccuracy in application of the crosshead may have led to premature contact of the bracket tie wings prior to contacting the bracket base. This force application would have had a torqueing force component as opposed to a pure shear bond force.

In future iterations of this study, it is recommended that each tooth is sectioned and individually mounted in acrylic. This will allow for more favorable force application to the bracket base in all directions. A narrower crosshead would make application of the force to the bracket base more predictable leading to more reliable recordings of shear bond strength.

More studies should be done in the future to test indirect bonding tray materials and their effects on light transmittance and depth of cure. Using controlled and appropriate tray thickness will likely lead to a reduction in the variation of the data, or at least more confidence in its accuracy.

VI. CONCLUSION

Efficiency is important in all orthodontic practices, and none moreso than those in the military setting where patients move frequently and troop dental readiness is of utmost importance. This study compared the shear bond strengths of three different orthodontic bonding systems that are currently available in the military orthodontic training program. One direct bonding group using Transbond XT adhesive was tested along with two indirect bonding groups using Revolution 2 flowable composite and Opal Bond Flow as the bonding adhesives. The results of the study show that the mean SBS of all three bonding methods exceed the minimum acceptable SBS required for clinical effectiveness. Direct bonding orthodontic brackets with Transbond XT had the highest mean shear bond strength of the three methods and also had a 100 percent clinical acceptability rate. Direct bonding with Transbond XT performed better than both Revolution 2 flowable and Opal Bond Flow. This difference in SBS and clinical acceptability rate was not significantly higher than the Revolution 2 flowable group, but it was significantly higher than the Opal Bond Flow group. This data suggests that direct bonding with Transbond XT would be the more ideal choice of the three methods tested for clinical success and efficiency, but the identified sources of potential error should leave the clinician skeptical of these results. More testing is needed with more tightly controlled bonding and testing protocols in order to more accurately evaluate the materials involved in this study.

VII. APPENDIX A

Shear Bond Strength Testing

Group 1			Group 2			Group 3		
Tooth #	SBS (N)	SBS (Mpa)	Tooth #	SBS (N)	SBS (Mpa)	Tooth #	SBS (N)	SBS (Mpa)
1.1	52.57	5.00	5.1	39.81	3.78	9.1	191.78	18.23
1.2	69.02	6.56	5.2	71.44	6.79	9.2	90.77	8.63
1.3	36.57	3.48	5.3	111.82	10.63	9.3	74.88	7.12
1.4	16.22	1.54	5.4	50.86	4.83	9.4	195.19	18.55
1.5	36.77	3.50	5.5	132.72	12.62	9.5	76.23	7.25
2.1	147.34	14.01	6.1	70.9	6.74	10.1	127.62	12.13
2.2	170.03	16.16	6.2	179.72	17.08	10.2	111.97	10.64
2.3	139.54	13.26	6.3	75.44	7.17	10.3	102.31	9.73
2.4	148.74	14.14	6.4	28.16	2.68	10.4	106.24	10.10
2.5	136.42	12.97	6.5	13.7	1.30	10.5	109.24	10.38
3.1	74.82	7.11	7.1	89.03	8.46	11.1	139.1	13.22
3.2	186.23	17.70	7.2	43.48	4.13	11.2	143.36	13.63
3.3	70.34	6.69	7.3	43.69	4.15	11.3	113.61	10.80
3.4	150.05	14.26	7.4	177.73	16.89	11.4	107	10.17
3.5	87.19	8.29	7.5	89.61	8.52	11.5	66.51	6.32
4.1	108.95	10.36	8.1	65.36	6.21	12.1	152.68	14.51
4.2	30.12	2.86	8.2	66.98	6.37	12.2	102.27	9.72
4.3	158.53	15.07	8.3	77.74	7.39	12.3	91.9	8.74
4.4	86.74	8.25	8.4	38.01	3.61	12.4	112.27	10.67
4.5	72.74	6.91	8.5	45.62	4.34	12.5	92.51	8.79
Avg =	98.95	9.41	Avg =	75.59	7.19	Avg =	115.37	10.97
StDev=	52.10	4.95	StDev=	45.18	4.29	StDev=	34.71	3.30

Table 2. Raw testing data

ANOVA

SBS

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	144.492	2	72.246	4.026	.023
Within Groups	1022.965	57	17.947		
Total	1167.457	59			

df = degrees of freedom F = F statistic

Table 3. Results of ANOVA

Multiple Comparisons

Dependent Variable: SBS

	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Tukey HSD	1	2	2.22150	1.33965	.230	-1.0023	5.4453
		3	-1.56050	1.33965	.479	-4.7843	1.6633
	2	1	-2.22150	1.33965	.230	-5.4453	1.0023
		3	-3.78200*	1.33965	.018	-7.0058	-.5582
	3	1	1.56050	1.33965	.479	-1.6633	4.7843
		2	3.78200*	1.33965	.018	.5582	7.0058
Bonferroni	1	2	2.22150	1.33965	.308	-1.0830	5.5260
		3	-1.56050	1.33965	.747	-4.8650	1.7440
	2	1	-2.22150	1.33965	.308	-5.5260	1.0830
		3	-3.78200*	1.33965	.020	-7.0865	-.4775
	3	1	1.56050	1.33965	.747	-1.7440	4.8650
		2	3.78200*	1.33965	.020	.4775	7.0865

*. The mean difference is significant at the 0.05 level.

Table 4. Post-hoc comparisons

G1: Revolution Flowable	Clinically Acceptable	G2: Opal Bond Flow	Clinically Acceptable	G3: Transbond XT	Clinically Acceptable
1.54	0	1.30	0	6.32	1
2.86	0	2.68	0	7.12	1
3.48	0	3.61	0	7.25	1
3.50	0	3.78	0	8.63	1
5.00	0	4.13	0	8.74	1
6.56	1	4.15	0	8.79	1
6.69	1	4.34	0	9.72	1
6.91	1	4.83	0	9.73	1
7.11	1	6.21	1	10.10	1
8.25	1	6.37	1	10.17	1
8.29	1	6.74	1	10.38	1
10.36	1	6.79	1	10.64	1
12.97	1	7.17	1	10.67	1
13.26	1	7.39	1	10.80	1
14.01	1	8.46	1	12.13	1
14.14	1	8.52	1	13.22	1
14.26	1	10.63	1	13.63	1
15.07	1	12.62	1	14.51	1
16.16	1	16.89	1	18.23	1
17.70	1	17.08	1	18.55	1
15/20 (75%)		12/20 (60%)		20/20 (100%)	

Table 5. Clinical acceptability scores

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